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Research Article

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Effect of long term soil fertilizer application on forms and distribution of potassium in soil under rice-cowpea cropping system

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Summary

An experiment was conducted at Zonal Agricultural Research Station, VC farm, Mandya to assess the effect of long term soil fertility management on behaviour of potassium with respect to different forms and distribution pattern in rice-cowpea cropping system. Soil of the study area belong to sandy loam texture having initial pH (6.28), EC (0.14 dSm^{-1}), CEC (9.60 cmol (p+) kg^{-1}), MWHC (20.70%) and bulk density (1.67 g cc^{-1}). The organic carbon (0.34 %), available nitrogen (163 kg ha^{-1}), available potassium (134 kg ha^{-1}) were low and medium in available phosphorus (29.20 kg ha^{-1}). Results indicated that the water soluble K content of soils varied from 8 to 16 mg K kg^{-1} in the surface layer and 5 to 14 mg K kg^{-1} in the sub surface layer in the plots treated with different fertilizer, manure and their combinations. Exchangeable K also ranged between 59 and 116 mg K kg^{-1} in the surface layer and 58 to 98 mg K kg^{-1} in the sub surface layer. The non-exchangeable K content ranged from 111 to 874 mg K kg^{-1} and from 160 to 880 mg K kg^{-1}, respectively in the upper and the lower layers. The total K content varied from 792 to 3017 mg K kg^{-1} at 0-15 cm depth and from 874 to 3318 mg K kg^{-1} at 15-30 cm depth.

Key words : Potassium, Forms, Distribution, Rice, Cowpea

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Introduction

Rice is one of the chief grains of India and has the biggest area under rice cultivation, as it is one of the principal food crops. The production of rice recorded during 2012 is about 104.32 m t. In most of the cropping systems practiced in India, potassium balance is negative, and this negative balance is often not reflected in available soil potassium status over years of cropping, long term fertilizer experiment are very useful to understand potassium dynamics in soil and its availability to crops which depends upon type of soil, climatic condition and cropping pattern. An ideal and practical approach to asses and management of potassium in agriculture may consist of obtaining a good understanding of the potassium status of a soil for knowing its different forms or fractions.

Potassium exists in soils as a structural element of soil minerals, fixed between clay mineral lattice, adsorbed on exposed surfaces of minute soil particles and in soil solutions. Potassium at the time of absorption by plant must exist in solution or exchangeable forms. The rate at which solution and exchangeable potassium are renewed by the lattice and non-exchangeable potassium, determines the significance of the quantities of solutions and exchangeable potassium. The amount of lattice and non-exchangeable K and the rate of release of potassium from the sources depend on the nature and abundance of potassium bearing minerals. The present study was undertaken to know the forms and distribution of potassium under continuous cropping and fertilizer application on rice based cropping system.

Resource and Research Methods

The details of materials used and methods followed in conducting experiments are described below.

Details of the experimental site :

The AICRP on Long Term Fertilizer Experiment was initiated at the Zonal Agriculture Research Station, VC Farm, Mandya at "I" Block during 1989-90. The soil is classified as Typic Rhodustalfs and is sandy loam in texture. There has not been any change either in cropping system or in fertilizer management practices since the inception of the experiment. The long term fertilizer experiment consists of permanently laid out plots in Randomized Block Design with sixteen treatments replicated two times.

Location: ZARS, V.C. Farm, Mandya
Season / year: *Kharif* 2012
Cropping system: Rice - Cowpea
Rice variety: Thanu (KMP - 101)
Date of sowing: 18 – 08 – 2012
Date of transplanting: 10 – 09 – 2012
Date of harvest: 12-01-2013
Spacing (cm): 20 x 10
No. of hills / plot: 5000
No. of seedlings / hill: 02
No. of replications: 02
Design: RCBD.

Methodology of the field experiment :

After land preparation, farm yard manure and green manure was incorporated into the soil two weeks in advance of transplanting date were in respective treatment. Fertilizers were added to the soil on the day of planting as per treatment details. Nitrogen was applied as urea, P as single super phosphate, K as muriate of potash and without sulphur plots were supplied with DAP (Di-Ammonium Phosphate).

Collection of soil samples :

Soil samples were collected from two depths (0-15cm and 15-30 cm) each plot of the experimental field before transplanting and after the harvest of rice crop.

Table A: Initial physico-chemical properties of experimental site recorded during 1989

Sr. No.	Properties/ parameter	value
1.	Mechanical composition	
	Coarse sand (%)	44.56
	Fine sand (%)	35.42
	Silt (%)	6.60
	Clay (%)	13.35
2.	Textural class	Sandy loam
3.	BD (g/cm^3)	1.67
4.	MWHC (%)	20.70
5.	Porosity (%)	24.50
6.	Hydraulic conductivity ($x10^{-5}ms^{-1}$)	4.10
7.	pH	6.78
8.	EC (d Sm^{-1})	0.13
9.	OC (%)	0.35
10.	CEC (c mol (p^+) kg^{-1})	12.30
11.	Available N (kg ha^{-1})	165.00
12.	Available P_2O_5 (kg ha^{-1})	28.90
13.	Available K_2O (kg ha^{-1})	122.50
14.	Exchangeable Ca (meq $100g^{-1}$)	1.25
15.	Exchangeable Mg (meq $100g^{-1}$)	0.38
16.	Available S (mg kg^{-1})	5.30
17.	DTPA extractable Zn (mg kg^{-1})	0.87
	Cu (mg kg^{-1})	2.20
	Mn (mg kg^{-1})	6.40
	Fe (mg kg^{-1})	42.3

Preparation of soil samples :

The soil samples collected were air-dried in shade, gently ground using wooden pestle and mortar to pass through 2-mm sieve. The sieved samples were preserved in stoppered plastic containers for further analysis.

Methods of soil analysis :

The soil samples used for various investigations were

analysed for mechanical separates and important chemical characteristics employing standard methods of analyses as detailed in Table B.

Statistical analysis :

The methods outlined by Panse and Sukhatme (1985) were made used for statistical analysis of the data for drawing conclusion on the effect of various treatments on different parameters studies. Simple correlation coefficients ('r') were also worked out for relationships among soil properties.

Reviews on potassium forms and distribution :

Potassium, a major plant nutrient element is often absorbed by plants in an amount equal to or greater than nitrogen. Potassium being unique in its distribution in soils, distribution of these forms is dependent upon two fundamental reactions *viz.*, fixation and release. Because of this complex nature, availability of K has become the subject of controversy and problem of research.

Different forms and distribution of K in soils :

Martin and Sparks (1983) classified the different forms of K based on the location in the soil system as follows:

Forms	Location
Water soluble	Soil solution
Exchangeable	Colloidal exchange sites in clay and organic matter
Non-exchangeable	Dioctahedral mica, Trioctahedral mica, hydrous mica
Mineral	K-feldspar, K-bearing minerals, micas.

Water soluble potassium :

Chatterjee and Sanyal (2007) found wide variability in soil K fractions in selected rice growing soils in the alluvial tract of West Bengal. The water soluble and exchangeable form of potassium varied to a greater extent (33.96 % and 52.87%, respectively).

Hebsur and Gali (2011) revealed that the mean water soluble K content varied from 2 to 7 ppm and 2 to 16 ppm in rice and sugarcane based cropping system in different agro climatic zones. Among two different cropping systems water soluble K was lower in rice based cropping system this could be due to leaching loss.

Exchangeable potassium :

Utpal and Ghosh (2011) reported the quantity of water soluble, exchangeable, non-exchangeable K decreased during the crop growing cycle both in the fertilized and unfertilized treatments in all the soils. Exchangeable K in the Inceptisols and non-exchangeable K in the vertisols decreased more significantly in the fertilized plots as compared to control.

Hebsur and Gali (2011) revealed that the mean exchangeable K ranged from 64 to 232 ppm and 148 to 281 ppm in rice and sugarcane based cropping system in

Table B : Analytical methods employed during chemical analysis

Sr. No.	Properties	Methodology	Reference
1.	Soil pH (1:2.5)	Potentiometry	Jackson (1973)
2.	Electrical conductivity	Conductometry	Jackson (1973)
3.	Organic carbon	Walkley and Black's wet oxidation method	Jackson (1973)
4.	Available nitrogen	Alkaline potassium permanganate method	Subbiah and Asija (1956)
5.	Available phosphorus	1: 0.03 N NH_4F and 0.025 N HCl (Acid soil) - Brays.	Jackson (1973)
		2 : 0.5M $NaHCO_3$ (Alkali or neutral soil)- Olsen	
6.	Available potassium	Neutral 1N NH_4OAc extraction and flame photometry	Jackson (1973)
7.	Forms of potassium	Flame photometry	
7a.	Water soluble-K	1:2 Soil water suspension	Maclean (1961)
7b.	Exchangeable-K	Neutral *N* Ammonium acetate extraction	Knudsen *et al*. (1982)
7c.	Non-exchangeable-K	Boiling *1N* Nitric acid extraction	Knudsen *et al*. (1982)
7d.	Total-K	Hydro-flouric acid extraction	Lim and Jackson (1982)
8.	K- fixing capacity	Alternate wetting and drying method	Jackson (1973)
9.	K-release characteristics	Successive extraction with *1N* boiling HNO_3	Haylock (1956)
10.	Plant-NPK	Tri-acid digestion	Piper (1966)

different agro climatic zones. Higher amount of exchangeable K ascribed due to the predominance of 2:1 clay minerals.

Non-exchangeable potassium :

Hebsur and Gali (2011) revealed that the mean non-exchangeable K ranged from 84 to 918 ppm and 205 to 1014 ppm in rice and sugarcane based cropping system in different agro climatic zones. Non-exchangeable potassium (NEK) showed wider variation among the soils which could be ascribed to their clay mineralogy.

Kyaw Ngwe *et al.* (2012) showed that the non-exchangeable K ranged from 6.42 to 744.32 mg kg^{-1} soil with an average of 163.78 mg kg^{-1} in lowland vertisols and showed that non-exchangeable K in the soil profiles generally decreased with increase in profile depth.

Lattice K :

Gurumurthy and Vagheesh (2007) observed that the mineral potassium in surface horizons varied from 0.88 per cent to 1.97 per cent in soils of transitional zones of Karnataka. The positive and significant correlation between total K and mineral K indicated that the soil K was in the lattice form.

Total K :

Total K in surface horizon varied from 0.93 to 2.10 per cent, while the maximum and minimum total K was observed in surface horizon of profile IV of Hirekerur taluk and profile II of Shimoga taluk soils, respectively (Gurumurthy and Vagheesh, 2007).

Research Findings and Discussion

The results pertaining to grain yield and straw yield of rice under long term fertility management practices in rice-cowpea cropping system is presented in the Table 1.

There was significant increase in grain yield and straw yield in the treatment 50% NPK+ 25%N-GM+ 25%N-FYM. This was attributed to the fact that there was a build-up of organic carbon which might have enhanced the productivity and efficiency of nutrients for optimum plant growth and biomass production (Mondal *et al.*,1994). Incorporation of organic manures along with applied fertilizer might have increased the availability of nutrients throughout the growth period which in turn increased the yield and yield attributes of rice crop.

Soil physico-chemical properties as influenced by long term soil fertility management in rice-cowpea cropping system :

The results pertaining to soil physico-chemical properties as influenced by long term soil fertility management in rice-cowpea cropping system is presented in the Table 2.

Table 1 : Effect of long term soil fertility management practices on rice grain and straw yield

Treatments	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
T_1 Control	1067	1399
T_2 100% PK	1971	2252
T_3 100%NK	2017	2162
T_4 STCR approach for targeted yield	4474	4859
T_5 100% NP	2128	2320
T_6 100% NPK+ Zn+ S	4108	4321
T_7 100% NPK+ Zn+ S+ FYM at 5 t ha^{-1}	5326	5622
T_8 100% NPK-Zn	3852	4112
T_9 100% NPK-S	3790	4003
T_{10} 100%N+50% P+50%K	2462	2740
T_{11} 50% NPK	2838	3147
T_{12} 50% NPK+ *Azospirillum*	3463	3628
T_{13} 50% NPK+50%N-green manure	4653	4876
T_{14} 50%NPK+50%N-FYM	4582	4721
T_{15} 50%NPK+25%N-GM+25%N-FYM	5683	6201
T_{16} FYM at 10 t ha^{-1}	4857	5110
S.E.±	153.88	40.51
C.D. (P=0.05)	444.15	116.92

The inorganic fertilizer treatments decreased the pH over the years of study. Continuous application of NPK fertilizer lowered the pH but when the addition of FYM, a fairly good source of basic cations particularly Ca, which hasens the soil physical properties. The soil pH was fairly good in FYM treated plot, it ranged from 5.28 to 6.45 in surface soil and 5.7 to 6.92 in sub-surface soil due to deactivation of Fe^{2+} and Al^{3+} by the chelating agents and concomitant release of basic cations upon its decomposition. Sub-surface soil recorded higher soil pH compared to surface soil; the reason for higher pH in subsoil as compared to surface soil might be attributed to higher amounts of clay as well as basic cations in lower layers (Ahmed, 2010).

EC recorded the highest 0.520dSm^{-1} in T_{15} and lowest 0.288 dSm^{-1} in T_1 in surface soil. However, the value remained less than 1.00 dSm^{-1} for any of the treatments. The same trend was observed in sub-surface soil showing highest EC value 0.369dSm^{-1} in T_{15} and lowest of 0.294 dSm^{-1} in T_1.

This may be due to the release of basic cations from the materials and subsequent formation of some of the soluble salts of those ions, The reason for relatively higher soluble salt contents observed in the FYM treated plots as compared to the plots treated with only chemical fertilizers could be attributed to the release of basic cations from the materials and subsequent formation of some of the soluble salts of those ions. The present study was in conformity with the results of Bhriguvamshi (1988) and Ahmed (2010).

The OC content ranged from 0.28 to 0.58 per cent in surface soil and 0.25 to 0.52 per cent in sub-surface soil. The reason for increase in organic carbon content in the plots treated with FYM might be due to the continuous addition of organic materials for several years from external sources as well as increased amount of crop residues added to the soil. There was significant variation in the soil organic carbon content among the treatments with incorporation of FYM alone or combination with chemical fertilizers.

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Table 2 : Soil physico-chemical properties as influenced by long term fertility management in rice-cowpea cropping system

Treatments	pH		EC (dSm^{-1})		OC (%)	
	0-15cm	15-30cm	0-15cm	15-30cm	0-15cm	15-30cm
T_1 Control	5.28	5.70	0.28	0.29	0.28	0.25
T_2 100% PK	5.58	6.05	0.40	0.32	0.38	0.28
T_3 100%NK	5.50	6.15	0.37	0.31	0.39	0.30
T_4 STCR approach for targeted yield	5.68	5.97	0.51	0.36	0.46	0.37
T_5 100% NP	5.30	6.05	0.36	0.29	0.35	0.29
T_6 100% NPK+ Zn+ S	5.65	6.10	0.37	0.26	0.36	0.26
T_7 100% NPK+ Zn+ S+ FYM at 5 t ha^{-1}	5.90	6.01	0.51	0.36	0.48	0.38
T_8 100% NPK-Zn	6.32	6.39	0.36	0.32	0.39	0.32
T_9 100% NPK-S	6.29	6.29	0.39	0.29	0.38	0.30
T_{10} 100%N+50% P+50%K	6.06	6.27	0.30	0.26	0.37	0.34
T_{11} 50% NPK	6.01	6.38	0.31	0.27	0.36	0.29
T_{12} 50% NPK+ *Azospirillum*	6.33	6.44	0.33	0.29	0.40	0.37
T_{13} 50% NPK+50%N-green manure	5.98	6.55	0.35	0.30	0.48	0.41
T_{14} 50%NPK+50%N-FYM	6.07	6.89	0.35	0.33	0.54	0.47
T_{15} 50%NPK+25%N-GM+25%N-FYM	6.45	6.92	0.52	0.36	0.58	0.52
T_{16} FYM at 10 t ha^{-1}	6.20	6.32	0.34	0.32	0.54	0.43
S.E.±	0.10	0.09	0.01	0.02	0.03	0.02
C.D. (P=0.05)	0.28	0.27	0.04	0.06	0.08	0.06

Note: STCR-Soil test crop response, GM-Green manure, FYM-Farm yard manure

The 50%NPK+25%N-GM+25%N-FYM has highest organic carbon content recorded 0.58 per cent. The reason for increase in organic carbon content in the plots treated with FYM might be due to the continuous addition of organic materials for several years from external sources as well as increased amount of crop residues added to the soil. This is in conformity with the findings of Kukreja *et al*. (1991).

The available nitrogen content in soil ranged between 239.5(kg ha^{-1}) to 371.5 (kg ha^{-1}) and 193.5 (kg ha^{-1}) to 324.5 (kg ha^{-1}) in upper and lower layers, respectively (Table 3). The higher content of available nitrogen in the surface soil may be due to the contribution of biomass addition from pulse crop *i.e.*, cowpea grown after rice crop since from 1998, which favoured to increase the biological nitrogen fixation capacity in *Kharif* season and in subsequent days. The amount of available nitrogen was relatively higher in the surface soil compared to sub-surface soil because the applied nitrogen content of soil and organic matter are directly related to each other and also solubility and availability of the element was more in top soil rather than the sub-surface soil. Similar results were reported by Kamaljit (2007).

The available phosphorus in the surface soil ranged from 18.20 to 55.65 kg ha^{-1} and 13.90 to 54.15 kg ha^{-1} in sub-surface soil. This may be due to organic matter content contributed to the available P pool of soil upon their mineralization (Badanur *et al*., 1990). Available phosphorus contents were much lower in the lower layers as compared to the upper layer of soil because phosphorus is not a mobile element in soil, if excess amount of inorganic fertilizer is added it may accumulate in the upper layer only (Ahmed, 2010).

The available potassium in the surface soil ranged from 142.5 to 320 kg ha^{-1} and 109.5 to 294.8 kg ha^{-1} in sub-surface soil. The treatment T_{15} has highest amount of available K this may be due to the continuous application of K fertilizer along with FYM. This FYM act as a reservoir of potassium and continuous release of K during decomposition increased the available K content significantly. Similar findings were reported by Kher and Minhas (1991). Farm yard manure is not only a direct but ready source of K but also aids in minimizing the leaching loss of K by retaining K ions on exchange sites of its decomposed products (Bansal and Sckhon 1992).

Correlation co-efficient :

Relationship (r) between physico-chemical properties of soil and grain yield of rice crop :

The grain yield of rice crop was correlated with physico-chemical parameters of surface soil (0-15 cm)

Table 3 : Primary nutrients (NPK) status of soil as influenced by long term fertility management practices in rice-cowpea cropping system

Treatments	Avl. N (kg ha^{-1})		Avl. P_2O_5 (kg ha^{-1})		Avl. K_2O (kg ha^{-1})	
	0-15cm	15-30cm	0-15cm	15-30cm	0-15cm	15-30cm
T_1 Control	239.5	193.5	18.20	13.90	142.5	109.5
T_2 100% PK	262.5	240.0	24.65	21.55	246.0	217.0
T_3 100%NK	279.0	275.0	24.50	21.90	223.0	203.5
T_4 STCR approach for targeted yield	327.5	321.5	41.10	38.80	308.0	280.0
T_5 100% NP	288.0	274.0	26.05	24.35	190.5	182.5
T_6 100% NPK+ Zn+ S	309.0	287.5	30.05	29.00	254.0	208.0
T_7 100% NPK+ Zn+ S+ FYM at 5 t ha^{-1}	349.5	326.5	46.95	43.60	322.0	291.0
T_8 100% NPK-Zn	299.0	274.5	26.40	22.95	255.0	208.0
T_9 100% NPK-S	292.5	258.0	26.45	22.45	278.5	215.0
T_{10} 100%N+50% P+50%K	301.5	287.5	26.20	22.75	241.0	219.0
T_{11} 50% NPK	320.5	298.0	26.70	23.25	271.0	212.5
T_{12} 50% NPK+ *Azospirillum*	368.0	327.5	41.40	39.15	288.0	231.0
T_{13} 50% NPK+50%N-green manure	358.0	313.0	44.25	32.55	280.0	235.5
T_{14} 50%NPK+50%N-FYM	362.0	312.0	48.90	43.50	271.5	248.0
T_{15} 50%NPK+25%N-GM+25%N-FYM	371.5	324.5	55.65	54.15	320.0	294.8
T_{16} FYM at 10 t ha^{-1}	346.5	291.0	38.90	30.70	259.5	227.5
S.E.±	11.36	10.44	2.16	1.40	10.74	7.38
C.D. (P=0.05)	32.78	30.14	6.24	4.03	31.00	21.30

Table 3a : Correlation co-efficient (r) among physico-chemical properties of soil and grain yield of rice crop in surface soil (0-15cm)

Parameters	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8
X_1 Crop yield	1	0.64^{**}	0.59^{*}	0.81^{**}	0.84^{**}	0.86^{**}	0.84^{**}	0.78^{**}
X_2 pH		1	0.10	0.54^{*}	0.66^{**}	0.52^{*}	0.67^{**}	0.58
X_3 EC			1	0.55^{*}	0.33	0.56^{*}	0.66^{**}	0.23
X_4 OC				1	0.75^{**}	0.86^{**}	0.68^{**}	0.77^{**}
X_5 Nitrogen					1	0.91	0.79	0.91
X_6 Phosphorus						1	0.77^{**}	0.88^{**}
X_7 Potassium							1	0.63^{**}

* and ** indicate significance of values at P=0.05 and 0.01, respectively

Table 3b : Correlation co-efficient (r) among physico-chemical properties of soil an grain yield of rice crop in sub-surface soil (15-30cm)

Parameters	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8
X_1 Crop yield	1	0.57^{*}	0.57^{*}	0.75^{**}	0.76^{**}	0.82^{**}	0.82^{**}	0.78^{**}
X_2 pH		1	0.18	0.77^{**}	0.57^{*}	0.60^{*}	0.50^{*}	0.71^{**}
X_3 EC			1	0.55^{*}	0.37	0.66^{**}	0.67^{**}	0.32
X_4 OC				1	0.70^{**}	0.82^{**}	0.69^{**}	0.83^{**}
X_5 Nitrogen					1	0.82^{**}	0.85^{**}	0.73^{**}
X_6 Phosphorus						1	0.85^{**}	0.82^{**}
X_7 Potassium							1	0.64^{**}

* and ** indicate significance of values at P=0.05 and 0.01, respectively

Table 3c : Correlation co-efficient (r) among physico-chemical properties of soil and straw yield of rice crop in surface soil (0-15cm)

Parameters	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8
X_1 Straw yield	1	0.64^{**}	0.62^{*}	0.82^{**}	0.83^{**}	0.86^{**}	0.84^{**}	0.77^{**}
X_2 pH		1	0.10	0.54^{*}	0.66^{**}	0.52^{*}	0.67^{**}	0.58^{*}
X_3 EC			1	0.55^{*}	0.33	0.56^{*}	0.66^{**}	0.23
X_4 OC				1	0.75^{**}	0.86^{**}	0.68^{**}	0.77^{**}
X_5 Nitrogen					1	0.91^{**}	0.79^{**}	0.91^{**}
X_6 Phosphorus						1	0.77^{**}	0.88^{**}
X_7 Potassium							1	0.63^{**}

* and ** indicate significance of values at P=0.05 and 0.01, respectively

Table 3d : Correlation co-efficient (r) among physico-chemical properties of soil and straw yield of rice crop in sub-surface soil (15-30cm)

Parameters	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8
X_1 Straw yield	1	0.56^{*}	0.59^{*}	0.75^{**}	0.75^{**}	0.83^{**}	0.83^{**}	0.77^{**}
X_2 pH		1	0.18	0.77^{**}	0.57^{*}	0.60^{*}	0.50^{*}	0.71^{**}
X_3 EC			1	0.55^{*}	0.37	0.66^{**}	0.67^{**}	0.32
X_4 OC				1	0.70^{**}	0.82^{**}	0.69^{**}	0.83^{**}
X_5 Nitrogen					1	0.82^{**}	0.85^{**}	0.73^{**}
X_6 Phosphorus						1	0.85^{**}	0.82^{**}
X_7 Potassium							1	0.64^{**}

* and ** indicate significance of values at P=0.05 and 0.01, respectively

are presented in the Table 3a. The grain yield of rice crop was found to be highly significantly and positively correlated with phosphorus (0.86**), nitrogen (0.84**) and potassium (0.84**). Nitrogen is highly significantly positive correlation with phosphorus (0.91**) and potassium (0.91**).

The grain yield of rice crop was correlated with physico-chemical parameters of sub-surface soil (15 – 30 cm), the corresponding 'r' values were presented in the Table 3b. Grain yield was highly significantly and positively correlated with phosphorus (0.82**), potassium (0.82**) and zinc (0.78**).

Correlation co-efficient (r) among physico-chemical properties of soil and straw yield of rice crop in surface soil and sub-surface soil :

Straw yield of rice crop was highly significant and positively correlated with phosphorus (0.86**), potassium (0.84**) and nitrogen (0.83**) in surface soil. Whereas, in sub-surface soil was highly significant and positive correlation with phosphorus (0.83**), potassium (0.83**) (Table 3c and 3d).

Distribution of potassium fractions in soil :

Water soluble K content of soils was low to high and varied from 8 to 16 mg K kg^{-1} in the upper layer and from 5 to 14 mg K kg^{-1} in the lower layer, in the plots treated with different fertilizer and manure combinations. The water soluble potassium content was higher in the surface soil compared to sub-surface soil, this may be due to greater amount of potassium bearing minerals to weathering conditions. The higher level of water soluble potassium was observed under 50% NPK+25% NGM+ 25% N-FYM. On decomposition of organic matter it releases the organic acids that would have released the potassium from fixed forms into available pool. Continuous application of FYM and NPK fertilizer enhanced the water soluble potassium to a considerable extent. The results are similar to Pannu *et al*. (2002) and Gurumurthy and Vagheesh (2007).

Water soluble potassium in soil was significantly lowered by crop growth and steep decrease of water-soluble K content in soil might be due its ability to replenish immediately (Ganeshmurty, 1981). Water soluble K may be referred as readily available potassium in soil was obviously high at surface zone compared to sub-surface due immediate replenishment of the same from the exchangeable pool.

Exchangeable K also varied from low to medium and varied from 59 to 116 mg K kg^{-1} in the surface layer and from 58 to 98 mg K kg^{-1} in the sub surface layer. K content of soil increased with increase in K fertilization (Thippeswamy *et al*., 2000) and addition of organic manures also enhanced the soil exchangeable K by supplying K into soil solution and ultimately acted as strong sink for K added. The integrated treatments *viz*., T_{15} 50%NPK+25%N-GM+25%NFYM), T_{14} (50%NPK +50%N-FYM), T_{13} (50%NPK+50%N-GM) and T_7 (100%NPK+Zn+S+FYM at 5 t ha^{-1}) showed consistent level of exchangeable K in these plots which might be due to continuous addition of K fertilizers under intensive cropping which helped to maintain the K status. The increasing trend of exchangeable K observed in surface soil compared to subsurface soil was reported by Sheela Swamy (2006).

A significant decrease in the soil exchangeable K was noticed in the plots T_1, T_6, T_{11} and T_{10} which was mainly because of the depletion of K due to crop removal (Utpal and Ghosh, 2011) and partly to the leaching of K with the colloidal fraction of the soil to the lower layers. The decreased content of exchangeable K at lower depths was mainly due to compact soil and less exchange sites available at that zone.

The non-exchangeable K content ranged from 111 to 874 mg K kg^{-1} and from 160 to 880 mg K kg^{-1}, respectively in the upper and the lower layer of soils.There was relatively higher amount of non-exchangeable K present in the lower depth of soils; the reason could be attributed to the presence of higher amount of clay and clay minerals in the second depth of soil. All the three forms of K were relatively higher in amounts with the addition of more organic manures continuously for longer period of time.

The lattice K content in surface soil varied from 545 to 1902 mg K kg^{-1} whereas in sub-surface soil the lattice potassium ranged between 573 and 2158 mg K kg^{-1} because the soils are which are generally having K-bearing minerals apart from which improvement in soil structure over the period due to continuous application of organic manures (Sharma *et al.,* 2007).

The total K content in different treatment combinations depended mainly on the improvement in soil physical properties and structure and also depended on K management practices, the content varied from 792 to 3017 mg K kg^{-1} at 0-15 cm and from 874 to 3318 mg K kg^{-1} at 15-30 cm depth. The highest total potassium

recorded in the treatment which received 50%NPK +25%N-GM+25%N-FYM, may is because of the presence of substantial quantities of K bearing minerals as a reserve since the treatment received sufficient amount of K from external application to meet out the crop demand (Gangopadhyay *et al*., 2005).

The amount of total K which depended largely upon the clay content and type of clay mineral present in the soils (Mehrotra *et al.*, 1973) might be the cause for huge amount of total potassium present in the lower depth of soils.

Correlation matrix (r-value) among different fractions of potassium in surface and sub-surface soil :

The 'r' values for potassium fixation in the surface soil were highly significant positive correlation with and different fractions of potassium were presented in the Table 4a and 4b. The potassium fixation showed was

Table 4 : Effect of long term soil fertility management on forms and distribution of potassium (mg 'K' kg^{-1}) in rice-cowpea cropping system

Treatments	Water soluble K		Exchangeable K		Non-exchangeable K		Lattice K		Total K	
	0-15cm	15-30cm	0-15cm	15-30cm	0-15cm	15-30cm	0-15cm	15-30cm	0-15cm	15-30cm
T_1	8	5	59	58	111	160	545	573	792	874
T_2	9	9	73	60	371	453	834	859	1381	1462
T_3	10	9	84	84	351	421	916	884	1465	1505
T_4	15	10	101	92	619	719	1864	1934	2772	2824
T_5	12	9	96	81	314	374	1217	1234	1766	1816
T_6	12	9	99	84	410	444	997	1036	1608	1713
T_7	14	10	104	94	628	631	1689	1707	2542	2585
T_8	11	8	98	92	493	510	855	875	1563	1590
T_9	10	7	102	78	497	499	850	884	1567	1583
T_{10}	10	9	107	84	454	466	790	809	1463	1506
T_{11}	11	10	99	85	518	545	467	499	1218	1242
T_{12}	11	10	101	86	417	430	718	1238	1862	1384
T_{13}	15	12	106	90	836	862	1660	1619	2714	2733
T_{14}	16	10	109	92	820	875	1783	1837	2882	2916
T_{15}	16	14	116	98	874	880	1902	2158	3017	3318
T_{16}	15	13	110	95	800	803	1800	1240	2284	2306
S.E.±	0.03	0.03	2.52	1.55	35.00	31.01	67.45	68.94	61.05	48.57
C.D. (P=0.05)	0.08	0.07	7.28	4.47	101.02	89.49	194.68	198.99	176.23	140.19

Note: STCR-Soil test crop response, GM-Green manure, FYM-Farm yard manure

Table 4a : Correlation matrix (r-value) among different fractions of potassium in surface soil (0-15cm) and available K in surface soil (0-15cm)

Parameters	X_1	X_2	X_3	X_4	X_5	X_6
X_1 Available -K	1	0.58^{*}	0.70^{**}	0.75^{**}	0.71^{**}	0.63^{**}
X_2 Water soluble -K		1	0.83^{**}	0.78^{**}	0.87^{**}	0.84^{**}
X_3 Exchangeable -K			1	0.91^{*}	0.96^{**}	0.89^{**}
X_4 Non- Exchangeable -K				1	0.87^{**}	0.74^{**}
X_5 Lattice -K					1	0.97^{**}
X_6 Total -K						1

* and ** indicate significance of values at P=0.05 and 0.01, respectively

Table 4b : Correlation matrix (r-value) among different fractions of potassium in sub-surface soil (15-30cm) and available K in surface soil (15-30cm)

Parameters	X_1	X_2	X_3	X_4	X_5	X_6
X_1 Available -K	1	0.53^{*}	0.78^{**}	0.79^{**}	0.80^{**}	0.75^{**}
X_2 Water soluble -K		1	0.68^{**}	0.73^{**}	0.62^{**}	0.54^{*}
X_3 Exchangeable -K			1	0.95^{*}	0.95^{**}	0.89^{**}
X_4Non- exchangeable -K				1	0.89^{**}	0.79^{**}
X_5 Lattice -K					1	0.98^{**}
X_6 Total -K						1

* and ** indicate significance of values at P=0.05 and 0.01, respectively

highly significant and positive correlation with non-exchangeable K (0.88**), exchangeable K (0.87**) in the sub surface fraction of soil potassium and highly significant and positive correlation with non-exchangeable K (0.87**), exchangeable K (0.87**) in the surface fraction of soil potassium.

The sub-surface fraction of potassium showed highly significant positive correlation with sub-surface K- fractions in that highly correlated with non-exchangeable k (0.84**) and total K (0.85**).

Conclusion :

Many long term fertilizer experiments clearly suggested the INM approach as best approach for better crop management in general.The above study particularly relates the INM approach to rice - cowpea cropping system with special relevance to behaviour of potassium to long term INM practice. The study reveals that under Cauvery command area, for maintaining the K supply power of these soils, regular application of K fertilizers along with organic manures is a necessity because of sandy loam texture of soil and poor water management. The study also focuses a better understanding on different fractions of potassium and their distribution also about the processes that affect the fate of added potassium under long term soil fertility management with special relevance to rice-cowpea cropping system.

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